

VANDERBILT UNIVERSITY



School of Engineering

# High-Speed Single-Event Current Transient Measurements in SiGe HBTs

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- **SiGe teams at the Georgia Electronic Design Center and IBM**
- **Naval Research Laboratory**
- **Sandia National Laboratories**
- **CEA, DAM, DIF (Arpajon, France)**

# Overview



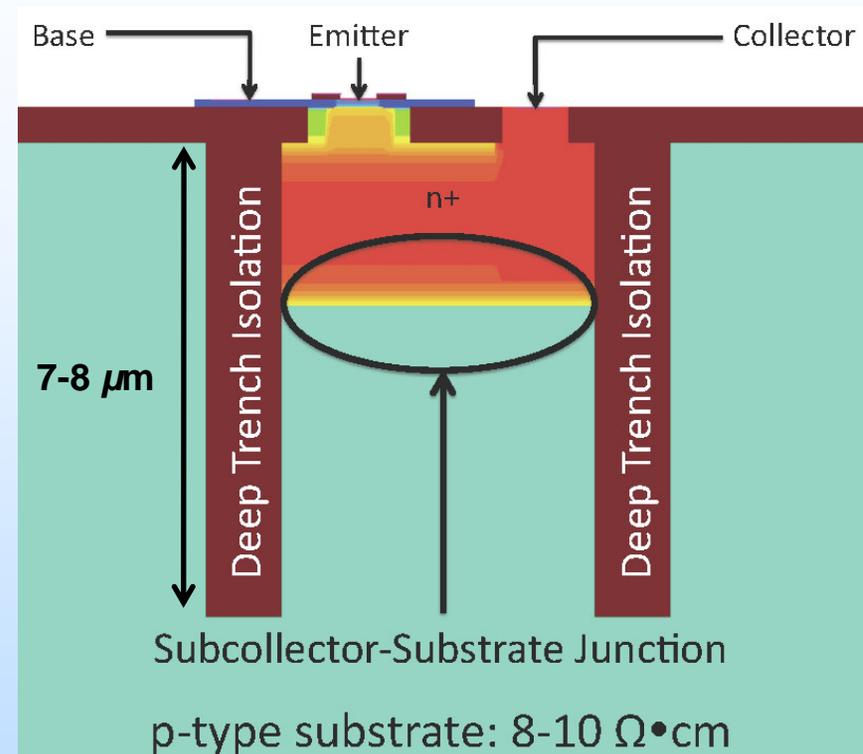
- **IBM 5AM SiGe HBT device background...briefly**
- **High-speed measurement setup**
  - Heavy ion microbeam, heavy ion broadbeam, pulsed laser
  - Advantages/disadvantages
- **Low-impedance current transient measurements**
- **Understanding what the transients represent for single-event effects in SiGe HBTs**

# Device Background and Introduction



- **Key device characteristics**
  - Deep trench isolation
  - Subcollector junction
  - Lightly-doped p-type substrate (large)
- **Extend state-of-the-art knowledge**

IBM 5AM SiGe HBT (0.5  $\mu\text{m}$ )



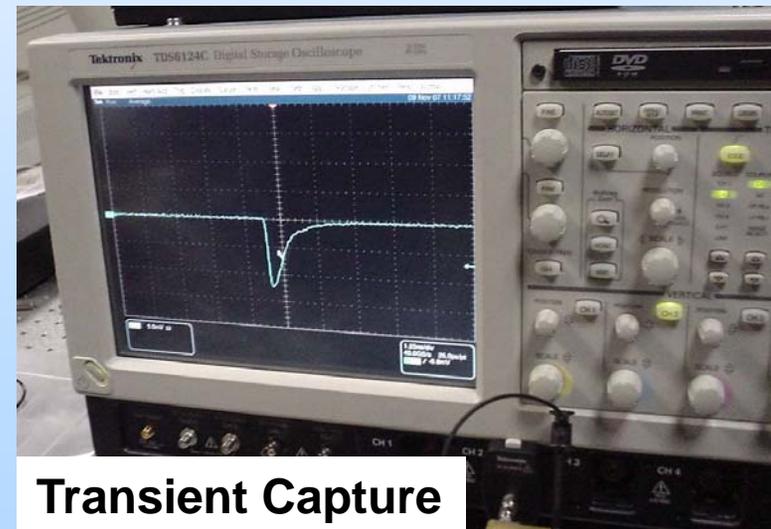
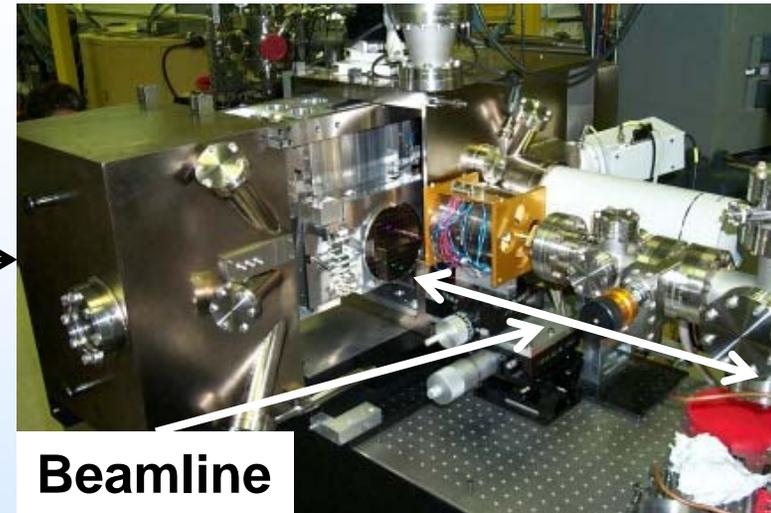
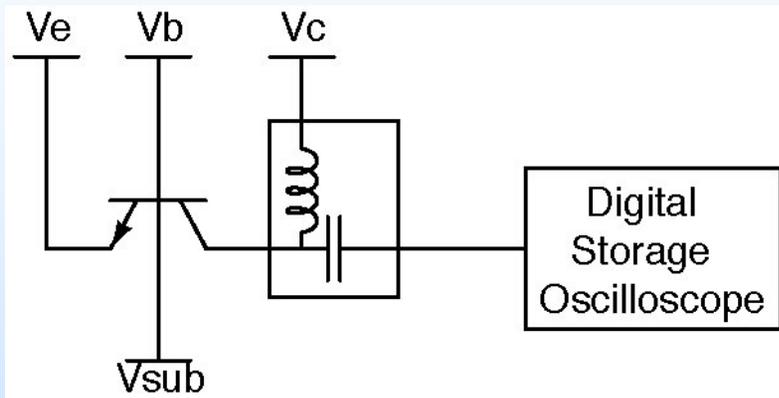
J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

**Previous tests focused on pulsed laser carrier generation only**  
**New tests focus on heavy ion carrier generation**

# Microbeam Experimental Setup



General electrical setup  
used in all cases

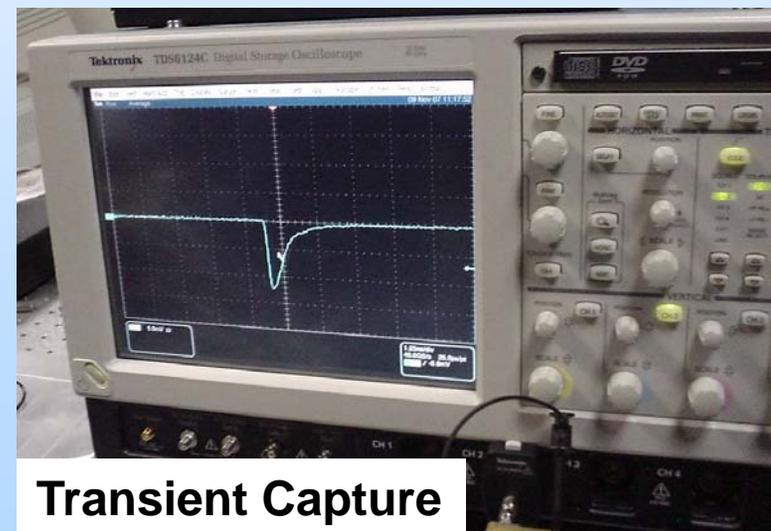
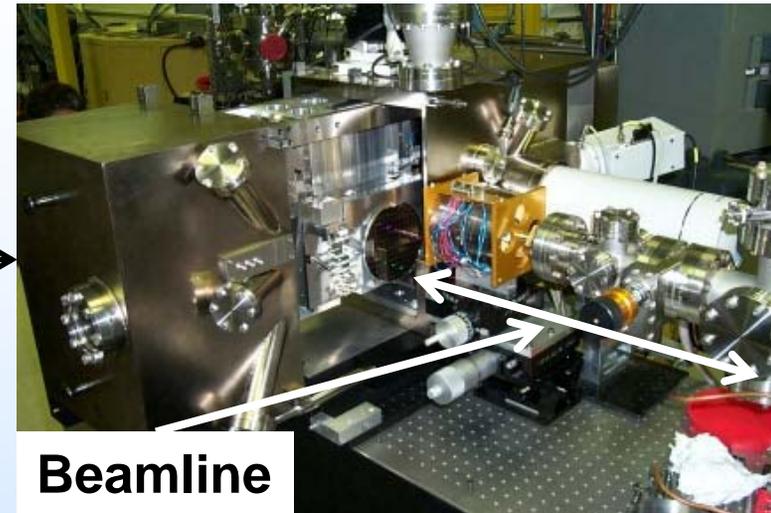
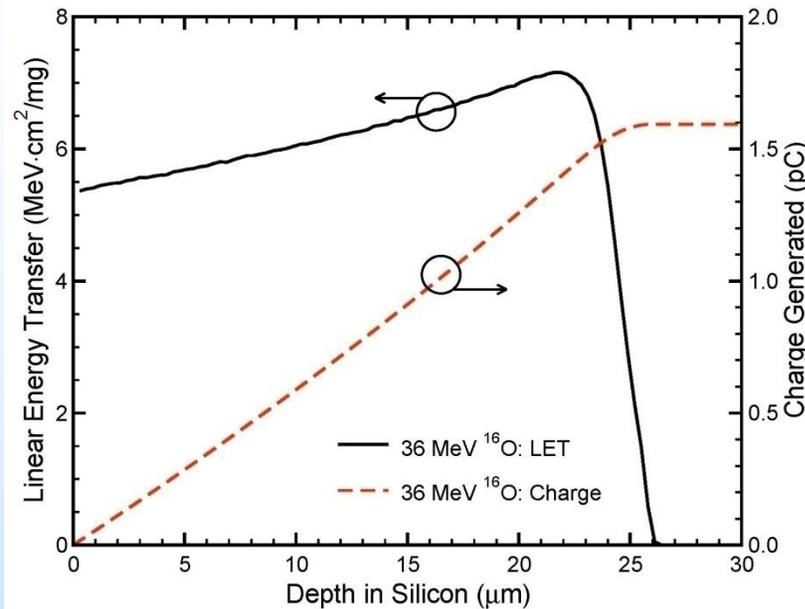


Similar setup for 4-terminal measurements

- PSPL Bias Tees: 5542K
- DPO/DSO: Tek 71604A (16 GHz; 50 GS/s), Tek 72004A (20 GHz; 50 GS/s)
- 2.9 mm coaxial cable assemblies (40 GHz)

Sandia National Laboratories'  
Microbeam Chamber

# Microbeam Experimental Setup

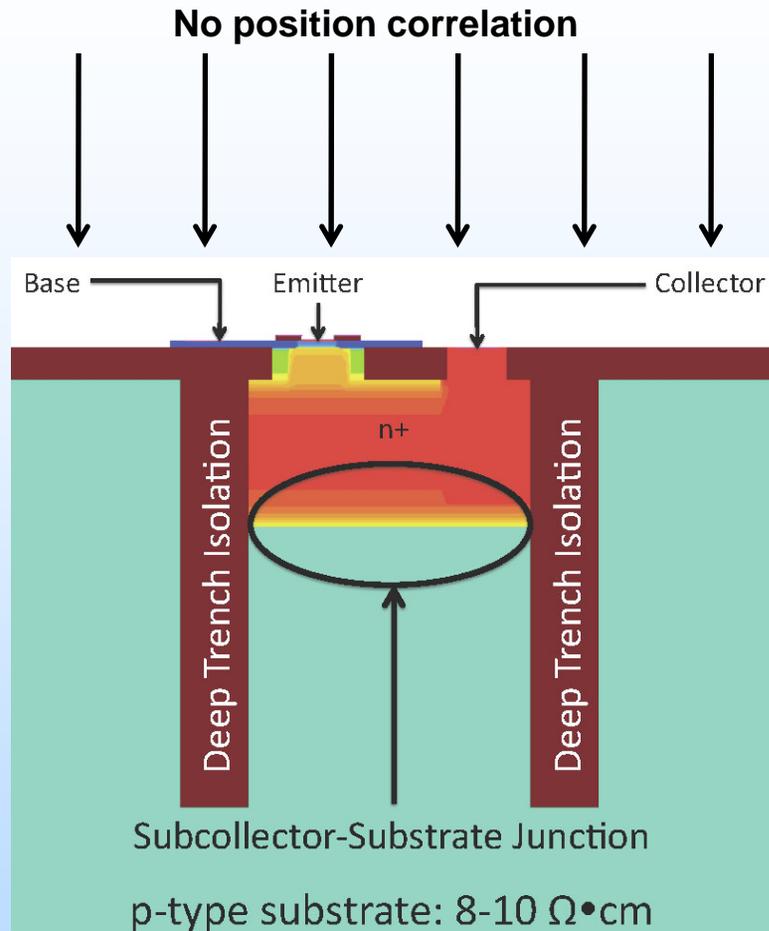


**36 MeV  $^{16}\text{O}$  dE/dx profile**  
[SRIM-2008]

**Sandia National Laboratories'**  
**Microbeam Chamber**

**\*\*Advantages/Disadvantages\*\***

# Heavy Ion Broadbeam Experiments



University of Jyväskylä  
K-130 Cyclotron

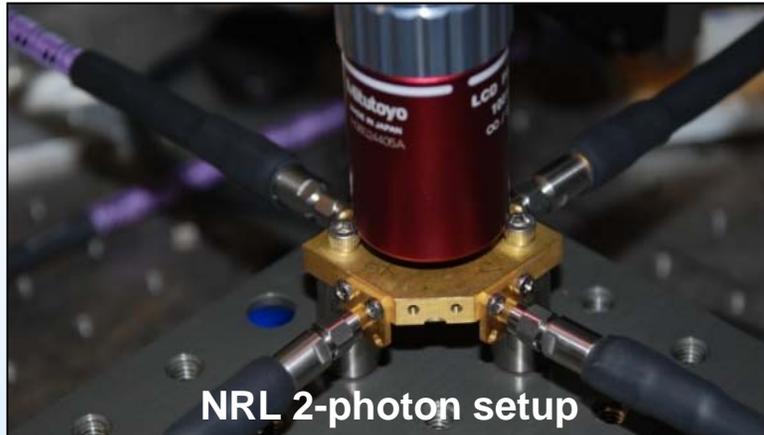


## **\*\*Advantages/Disadvantages\*\***

- Data collection at the University of Jyväskylä, Finland and GANIL, France
- 9.3 MeV/u cocktail including  $^{20}\text{Ne}$ ,  $^{40}\text{Ar}$ ,  $^{82}\text{Kr}$ , and  $^{131}\text{Xe}$  and 45.5 MeV/u  $^{136}\text{Xe}$

To be presented by Jonathan A. Pellish at the 2009 MURI Review, Vanderbilt University, Nashville, TN on 11/June/2009  
and published on <http://radhome.gsfc.nasa.gov/>, <http://www.nepp.gov/>, and <http://www.isde.vanderbilt.edu/>

# Two-Photon Absorption Testing

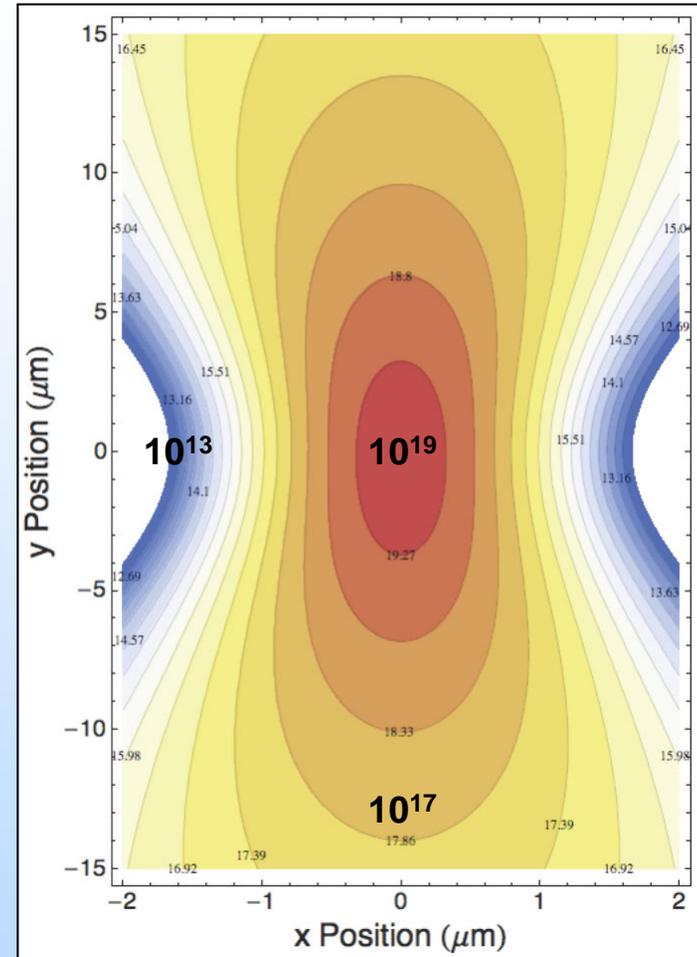


NRL 2-photon setup

Six 2.9 mm coaxial connectors



Custom High-Speed Package



Units are (e-h pair/cm<sup>3</sup>)

1260 nm TPA Electron-hole pair density contour

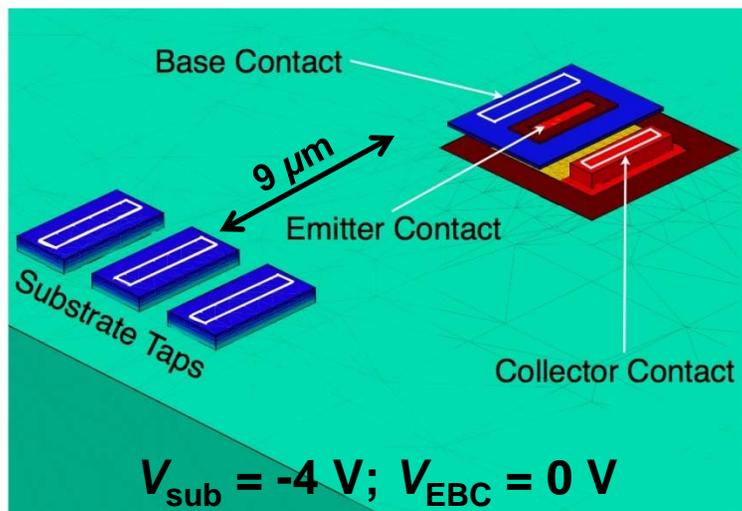
Electron-hole pair charge packet positioned at DUT in all three dimensions

J. A. Pellish *et al.*, *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.

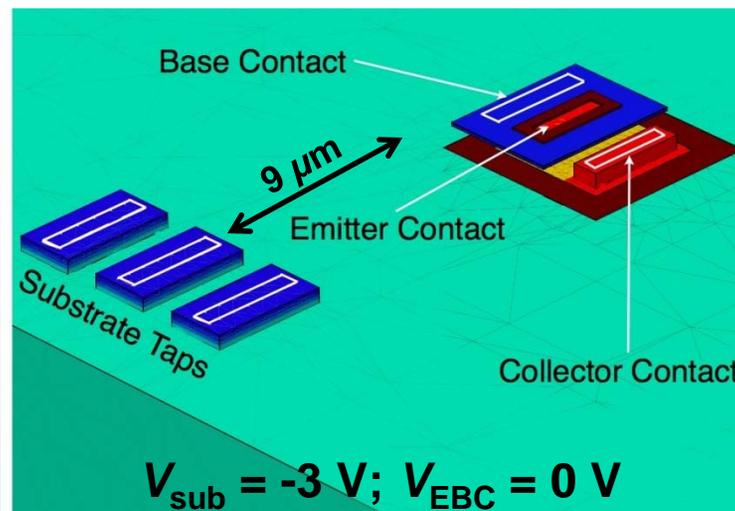
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# Bias Conditions of Interest

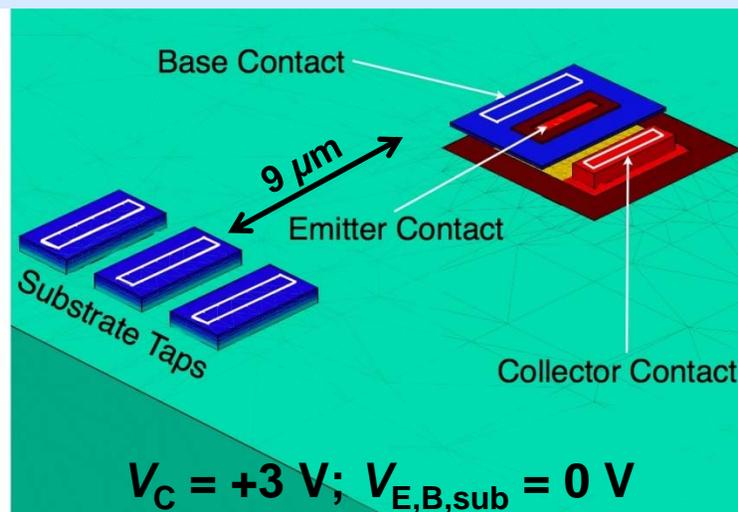
CASE 1



CASE 3



CASE 2



- 3-D TCAD
- Rendering from GDSII of actual DUTs

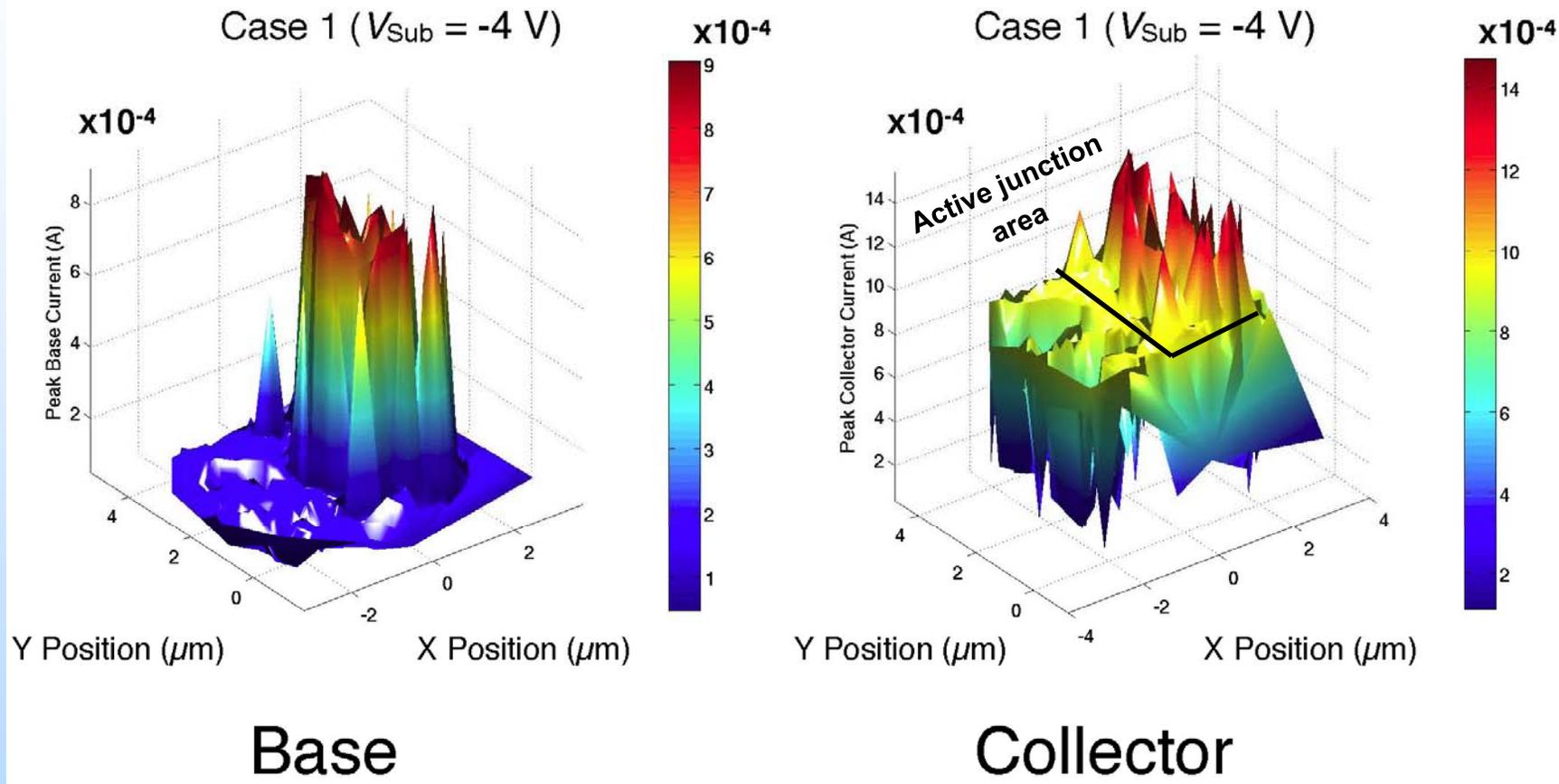


# Heavy Ion Microbeam Transients

# 36 MeV $^{36}\text{O}$ Microbeam Data: Case 1



## Peak Current Magnitude

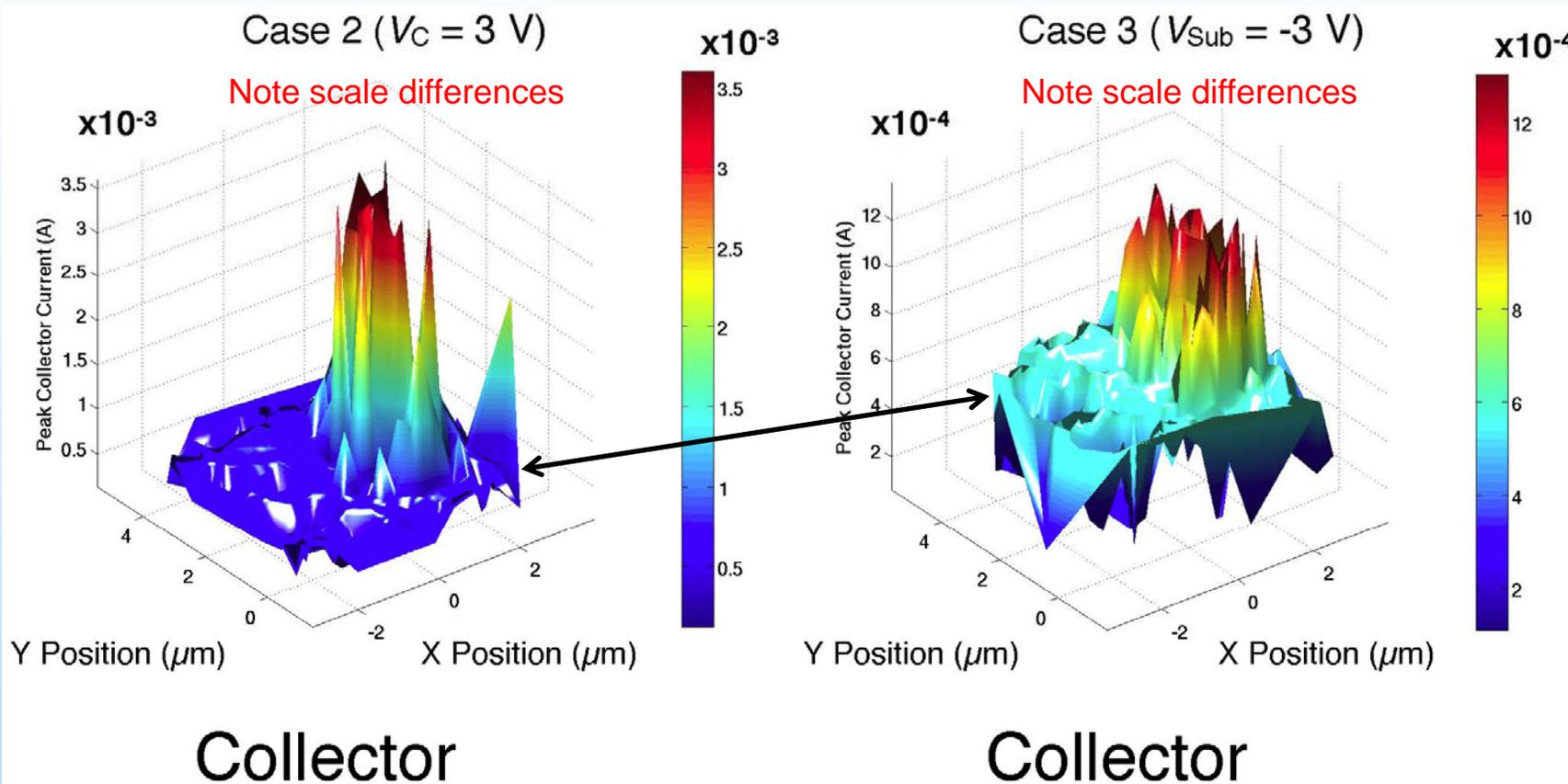


- Base terminal images base-collector junction
- Collector terminal images base-collector junction and subcollector

# 36 MeV $^{36}\text{O}$ Microbeam Data: Cases 2 & 3



## Peak Current Magnitude

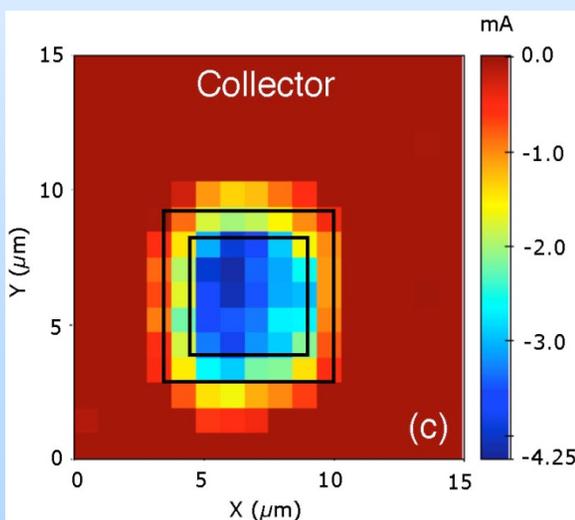
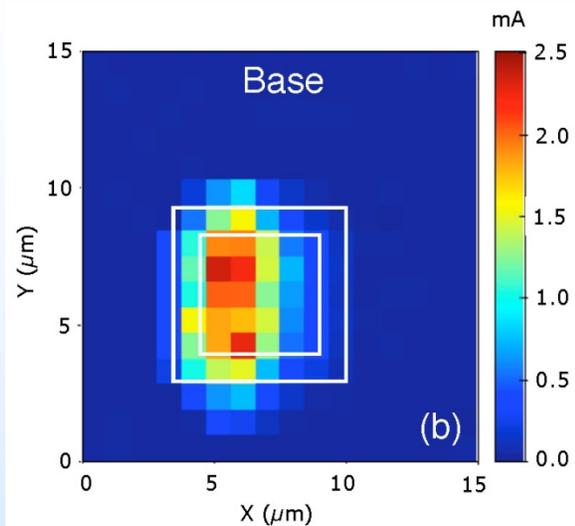


- Significant current magnitude increase for  $V_C = +3\text{ V}$
- Observed in two-photon pulsed laser testing too

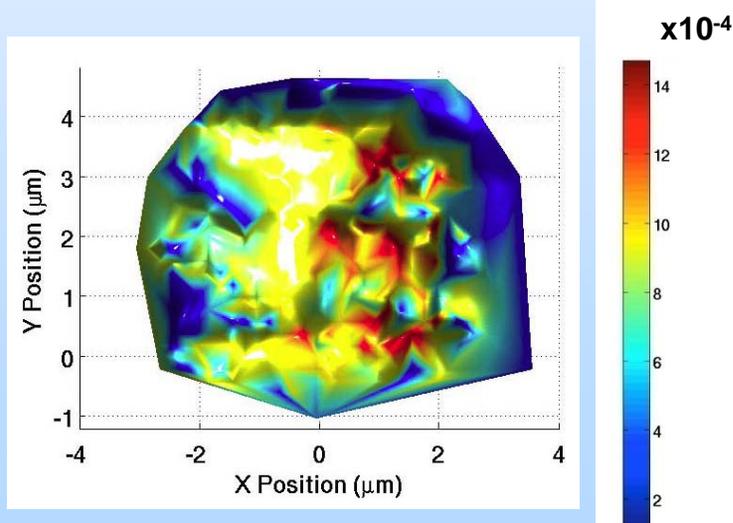
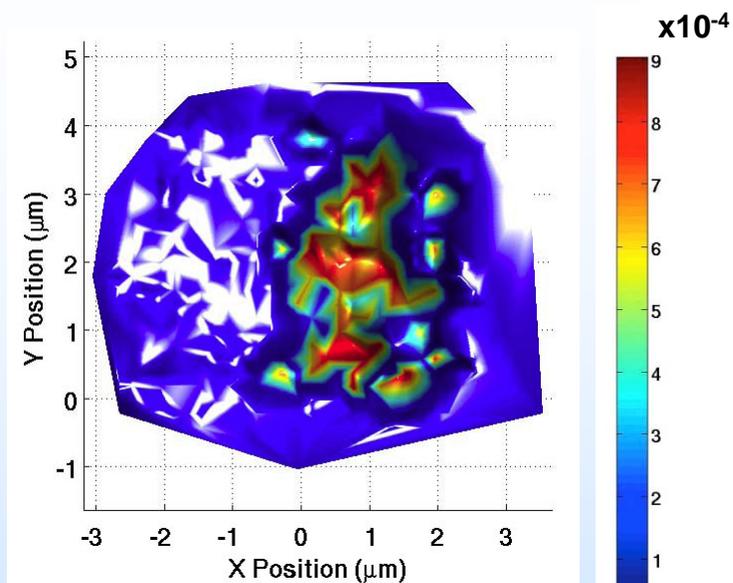


# TPA Pulsed Laser vs. Microbeam

J. A. Pellish et al., *IEEE Trans. Nucl. Sci.*, vol. 55, no. 6, p. 2936, Dec. 2008.



Both data sets for  
**CASE 1**  
( $V_{\text{sub}} = -4 \text{ V}$ )



**TPA Pulsed Laser**

**Microbeam**

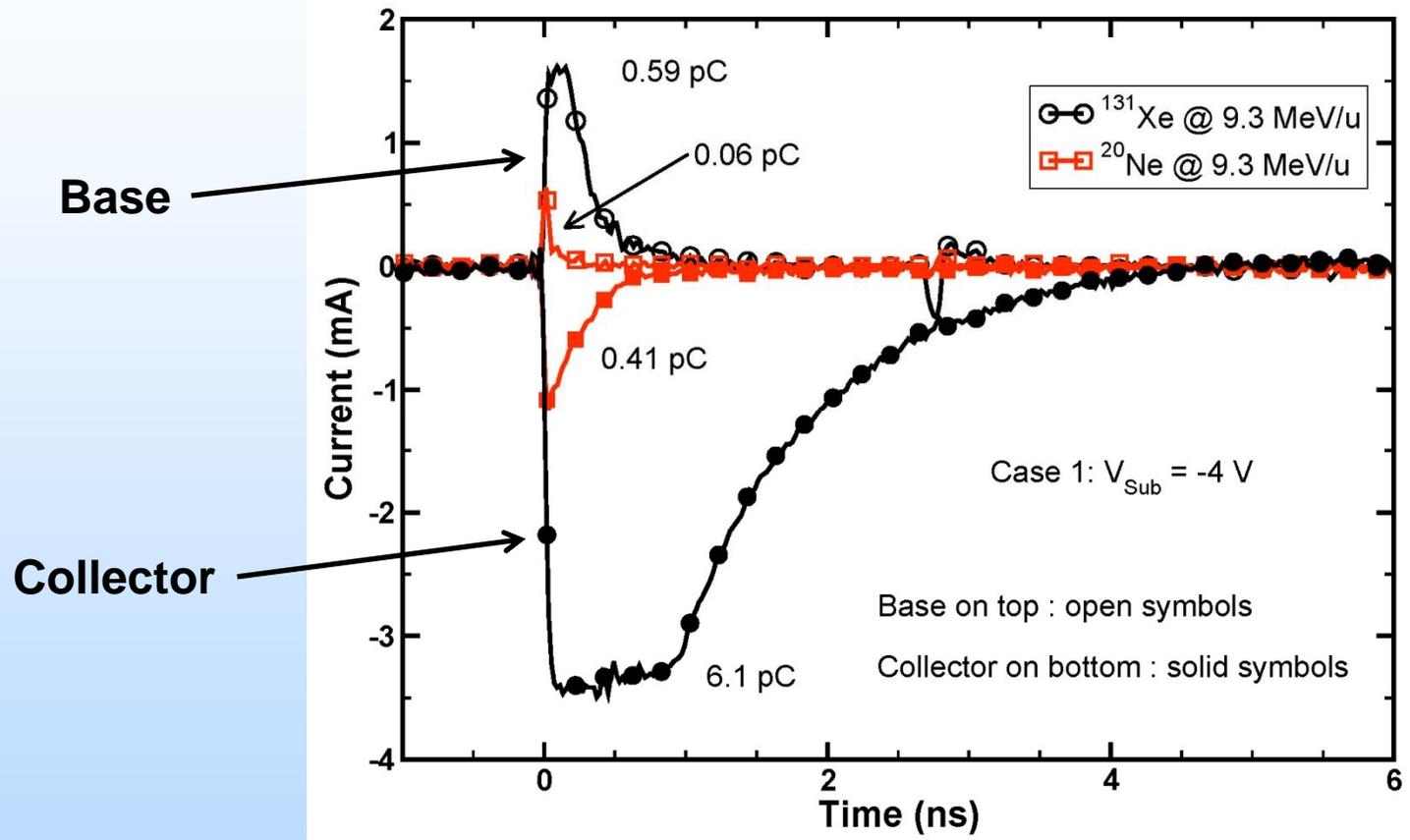
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# Heavy Ion Broadbeam Transients



# JYFL Broadbeam Transients

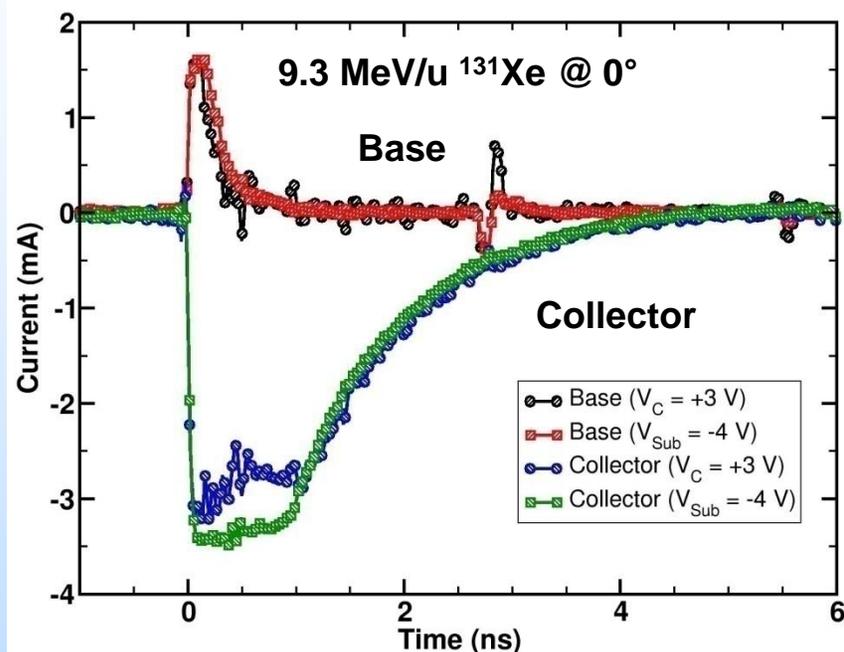
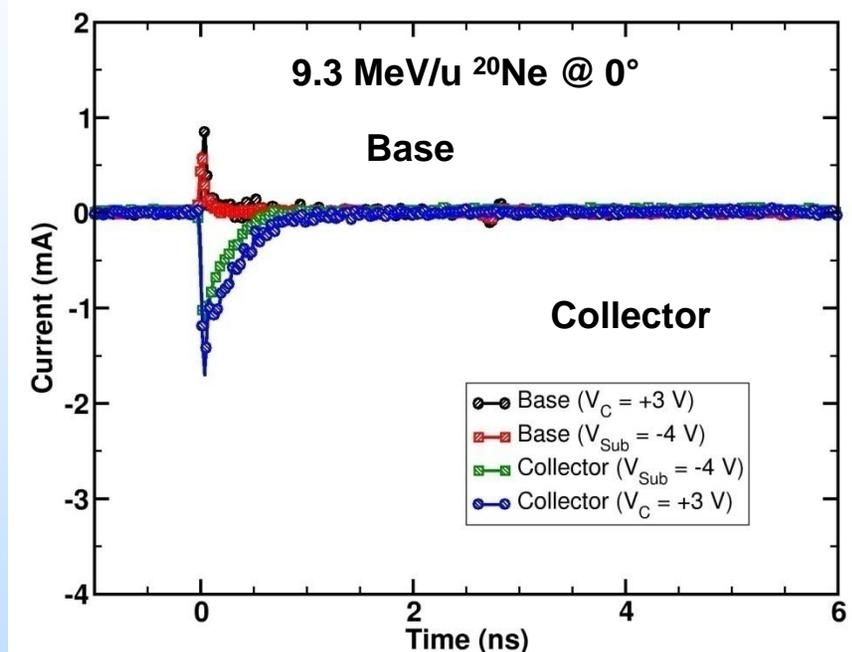


- Typical events observed from events somewhere within active region
- Position inferred using SNL microbeam data



# JYFL Broadbeam Transients

Maximum amplitude transients as a function of bias

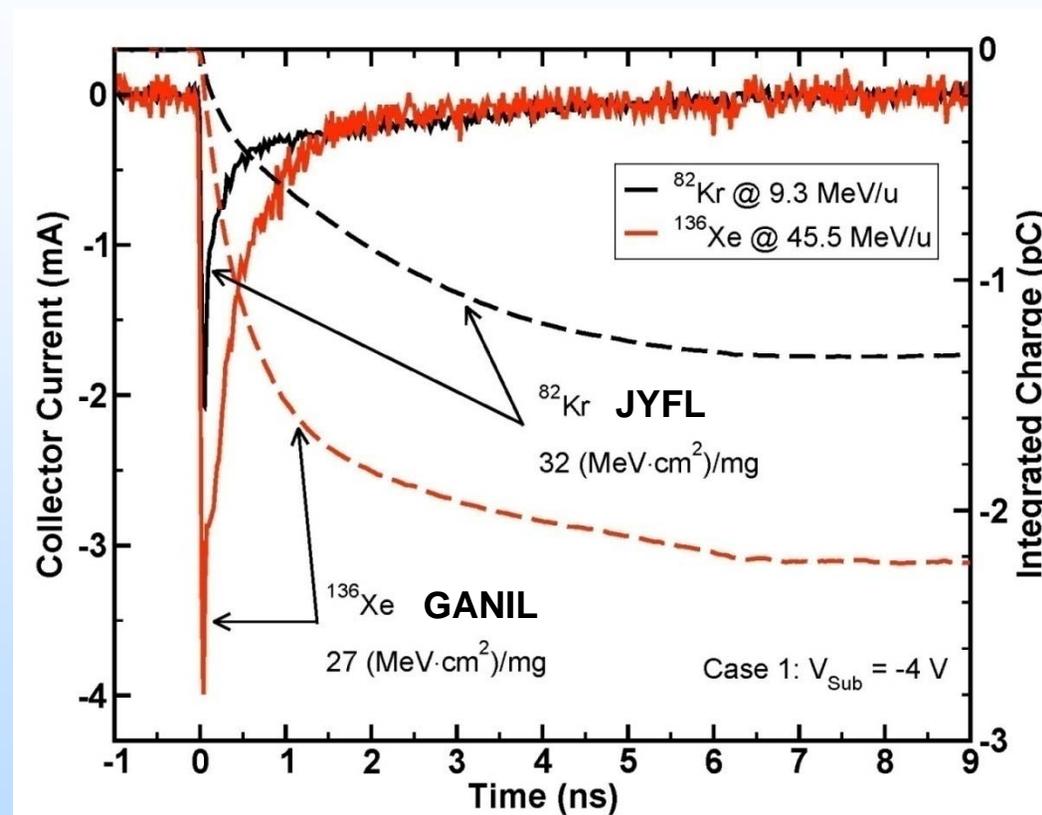


- Saturation of collector current transient with highly ionizing particle
- Some bias dependence, but masked by random hit location

# JYFL vs. GANIL Broadbeam Transients



Ion  
Range



Recombination

- Similar LET values produce different transient responses
- Trend holds for average of all transients for each LET



# Path Forward

- **Attempt to uncover reason for increase in collector current for  $V_C = +3$  V bias condition**
  - Impact ionization, bias scheme or other positive feedback
- **Uncover role of ion range and recombination mechanisms in lightly-doped substrates**
  - GANIL 45.5 MeV/u  $^{136}\text{Xe}$  vs. JYFL 9.3 MeV/u  $^{82}\text{Kr}$
- **Build new devices and circuits with matching networks to provide appropriate impedances**
  - Both “looking in” and “looking out”



# Summary

- **Time-resolved ion beam induced charge reveals heavy ion response of IBM 5AM SiGe HBT**
  - Position correlation
  - Unique response for different bias schemes
  - Similarities to TPA pulsed-laser data
- **Heavy ion broadbeam transients provide more realistic device response**
  - Feedback using microbeam data
  - Overcome existing issues of LET and ion range with microbeam
- **Both micro- and broadbeam data sets yield valuable input for TCAD simulations**
  - Uncover detailed mechanisms for SiGe HBTs and other devices fabricated on lightly-doped substrates
  - What type of device transient constitutes a circuit effect?